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Analysis of Electrical Fire Investigations in Ten Cities

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Fire Research
Washington, DC 20234

December 1983

Final Report

Sponsored by:
U.S. Consumer Product Safety Commission
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John R. Hall, Jr., Richard Bukowski and Alan Gomberg*

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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ANALYSIS OF ELECTRICAL FIRE INVESTIGATIONS IN TEN CITIES

John R. Hall, Jr., Richard W. Bukowski and
Alan Gomberg*

Abstract

This report describes the results of an analysis of electrical fire cases by the Center for Fire Research, National Bureau of Standards for the Consumer Product Safety Commission. The report describes the 105 detailed electrical fire investigation reports from 10 participating cities and discusses findings resulting from analysis of the data from those reports. These findings include the effects of tampering, alterations and other system problems, factors that may cause overcurrent devices to fail to operate, the role of extension cords misused as permanent extensions of building wiring, the problems of loose connections between receptacles and wiring, and other scenarios and sequences of events that lead to electrical fire ignition.

Key Words: Electrical fires

1. INTRODUCTION

This report describes characteristics and patterns of 105 electrical fires, with special attention to those patterns that suggest hypotheses on fire prevention programs and product design. Data for this analysis were collected in 10 cities, as shown in table 1. The Consumer Product Safety Commission (CPSC) sponsored the research and suggested an initial set of issues to be examined. The Federal Emergency Management Agency, U.S. Fire Administration (USFA) and its consultant, John Ricketts, collected the data and implemented a training program on the identification of electrical fires for fire department personnel in these 10 cities. The resulting detailed electrical fire investigation cases were provided to the Center for Fire Research (CFR) for review, coding and analysis. All electrical fires investigated occurred during the period of March 1980 through December 1981, but the actual period of data collection varied from city to city.

The intent of this analysis was to identify patterns that could suggest hypotheses regarding the nature of significant electrical failures, the electrical distribution components involved in fire origination, and the identification of the mechanisms resulting in component failure. These results could then be used to assign priorities in further efforts aimed at understanding electrical fire problems and the potential effects of actions aimed at remedying those problems.

This analysis was done in two stages. The initial analyses, documented in the Interim Report, used 110 cases, excluding only the Oakland case in age-of-building analyses for reasons cited later. In the second phase, five more

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Table 1. Electrical Fire Cases by City

City	No. of Cases
Akron, Ohio	22
Grand Rapids, Michigan	4
Long Beach, California	8
Oakland, California	1
Portland, Oregon	10
Sacramento, California	13
San Diego, California	7
San Francisco, California	16
San Jose, California	11
Toledo, Ohio	13
Total	105

NOTE: An additional nine cases were provided. Four could not be included in the analysis because of incomplete documentation and inadequate detail. Five fires were dropped after completion of the Interim Report because a second-stage analysis indicated they probably were not electrical in origin.

cases were dropped because those fires were not of electrical origin. These five cases have been removed from both the initial analyses and the new analyses.

2. DESCRIPTION OF WORK

The detailed investigations used a fire incident report and a two-part questionnaire, with one part containing general information on the electrical system and the second part containing detailed information on the electrical component involved. The questionnaire is not reproduced here due to its length. Copies may be obtained from Linda Smith, U.S. Consumer Product Safety Commission, Division of Hazard Analysis/Epidemiology, Washington, D.C. 20207. In addition, most of the cases included photographs and detailed electrician's reports, including schematics of the buildings' electrical systems and other relevant details. Approximately one third of the cases also included damaged components.

The detailed investigations were made based on preliminary field determination of electrical origin by the responding fire company and subsequent confirmation by fire investigators. After the completion of each investigation, the completed questionnaires, photographs and samples were sent to the USFA consultant, Mr. Ricketts, who reviewed them and contacted the investigators as necessary to clear up questions and problems. The completed cases were then passed to CFR, through CPSC, for coding and analysis.

The coding was screened by personnel skilled in electrical engineering, who used the following procedure: The principal investigator coded each case, using the investigator reports, photographs and physical samples where available. The points on which he felt further input was needed were identified. An NBS electrical engineer then provided the needed input. (This procedure of input only as deemed necessary was first tested on a random sample of ten cases, with the electrical engineer reviewing all coding, not just items where input was requested.) Input from the electrical engineer proved necessary in approximately one third of the cases.

The computer coding was set up according to a three-part format which also roughly corresponds to the organization of the material in this report. First, the incident report data were coded using the data elements and conventions employed in the National Fire Incident Report System (NFIRS) [1][1]. (Most cities included incident reports prepared for NFIRS or using a similar format.) Analyses of this information are contained in section 3 of this report. Second were the general descriptions of electrical systems, based on Part 1 of the questionnaire. Analyses of this information are contained in section 4 of this report. Third were the detailed descriptions of the particular electrical components involved in the fires. Analyses of patterns for each major type of component are contained in sections 8 through 12 of this report. Sections 5 through 7 of this report deal with issues that need to be examined both relative to all components and relative to each major type of

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[1] Numbers in brackets refer to the literature references listed at the end of this paper.

component involved in ignition. These issues are characteristics and performance of overcurrent protection devices, the role of building age, and the role of thermal insulation.

3. OVERVIEW OF CHARACTERISTICS OF FIRE INCIDENTS

This section presents some major patterns based on tabulations of key Incident Report parameters. Subsequent sections present an overview of some electrical report information and more detailed examinations of failure modes and key characteristics and present significant findings and hypotheses.

Following are brief definitions of the Incident Report parameters examined.

Fixed Property Use - The type of property in which the fire occurred.

Area of Origin - The room or space where the fire originated.

Detector Performance - The presence or absence of smoke detector(s) and their functioning.

Extent of Flame Damage - The final extent of flame and heat damage due to the fire.

Time of Fire - Usually the time (often shortly after ignition) that the fire was reported to the fire department.

Occupant Condition - A description of the occupancy of the structure just prior to the fire (all occupants asleep, at least one occupant awake, etc.).

Equipment Involved in Ignition - The equipment which provided the heat which started the fire (fixed wiring, cord, plug, etc.).

Form of Heat of Ignition - The form of the heat energy igniting the fire (water caused arc, arc from mechanical damage, etc.).

3.1 Fixed Property Use

Most cases (86 percent) were single family dwellings, with the remainder either duplexes (eight percent) or small apartments (up to six units) (seven percent). By design, no fires in large apartment complexes (containing over six units) were investigated. This distribution compares well with national Census estimates of occupied housing units for 1978, which indicate that 84 percent of the occupied housing that contains four or fewer individual units are single unit and 16 percent are structures containing two to four dwelling units [2]. In other words, there was no indication that some types of housing, within this limited set, were more prone to electrical fires than others.

3.2 Area of Origin

The area of fire origin was coded in NFIRS format. The results are tabulated in table 2. Concealed spaces - within ceiling, walls and attics -

Table 2. Area of Origin

Area		Percent of Total
Bedroom		17.1
Living Room		7.6
Basement		7.6
Kitchen		6.7
Garage		4.8
Dining Room		1.9
Closet		1.0
Concealed Space - Wall		21.0
Concealed Space - Attic		15.2
Exterior Wall Surface		7.6
Concealed Space - Ceiling		5.7
Crawl Space		1.0
Other		2.9
	Total	100.0

were the leading areas of origin, totaling 42 percent of all fires. Only 33 percent of the fires started in the normally occupied living areas, i.e., living rooms, bedrooms, kitchens and dining rooms.

As would be expected, the majority (73 percent) of branch circuit wiring fires occurred in concealed spaces. Those that were not in concealed spaces included legitimate locations, like wiring in basements with exposed rafters, and illegitimate locations involving exposed wiring in places where wiring should not be exposed. In addition, 56 percent of the fires involving receptacles were in concealed spaces. (Fires that began behind the switchplate in the receptacle were in concealed spaces. Fires caused by receptacle faults but occurring outside the switchplate, for example in a plug, were coded as receptacle fires occurring in unconcealed spaces.)

Together these two components accounted for 73 percent of the concealed space fires. For fires in living areas, the dominance of bedroom fires is accounted for by cords and plugs, which were involved in 67 percent of the bedroom fires. Almost half (44 percent) of the cord and plug fires in the data base occurred in bedrooms.

3.3 Equipment Involved in Ignition and Form of Heat of Ignition

These data elements are compared in table 3.

Several combinations of Equipment Involved and Form of Heat stand out in table 3. Loose and faulty connections (38 percent of cases with known Form of Heat) are the leading Form of Heat for fixed wiring, although mechanical damage (22 percent of known cases), defective or worn insulation (19 percent of known cases) and overloaded equipment (19 percent of known cases) are well represented. Loose and faulty connections (62 percent of known cases) also dominate the Equipment Involved category of switch, receptacle, outlet. The cord and plug Equipment Involved category is dominated by mechanical damage (46 percent of known cases) and overloaded equipment (33 percent of known cases).

The other equipment categories have no dominant Form of Heat. Further analysis of some of these patterns, using the more detailed data in the Part 1 and Part 2 reports, can be found in the subsequent sections, which address the primary electrical components involved in ignition. The breakdown of this more detailed data is not directly comparable with the NFIRS type coding for equipment involved, however, due to differences in the coding formats.

3.4 Detector Performance

The presence or absence of detectors was established in 94 of the 105 cases. They were present in 17 percent of the 94 cases. This compares with the 1980 national estimates, which show detectors present in 20 percent of all fires in one- and two-family dwellings and small apartments. The fact that detectors are known to have been present in about one half of all households in the country in 1980 [3] and were present in only 17 percent of the fires in this data base indicates that homes with smoke detectors may be less likely to

Table 3. Equipment Involved in Ignition* Versus Form of Heat of Ignition

Equipment Involved in Ignition	Form of Heat of Ignition							Total Number	Total Percent
	Water Caused	Mechanical Damage	Defective, Worn Insulation	Loose, Faulty Connection	Overloaded Equipment	Other	Unknown, Unspecified		
Fixed Wiring	1	7	6	12	6	0	7	39	(37)
Switch, Receptacle, Outlet	0	2	1	8	2	0	5	18	(17)
Light Fixture, Lampholder	0	1	1	3	2	3	0	10	(9)
Cord, Plug	1	11	1	3	8	0	3	27	(26)
Lamp, Light Bulb	0	0	0	1	0	3	0	4	(4)
Other	2	0	1	0	3	0	1	7	(7)
Total Number	4	21	10	27	21	6	16	105	
Total Percent	(4)	(20)	(9)	(26)	(20)	(6)	(15)		(100)

*Note that this is the NFIRS coding format for equipment involved in ignition. It is not directly comparable with the component involved in ignition given in table 8 and elsewhere in this report. Fixed wiring, for example, includes Branch Circuit Wiring and several categories of service component wiring.

have a reported electrical fire than homes without or that such homes may be more likely to control such fires without having to report them to the fire department or both.

3.5 Extent of Flame Damage

The final extent of flame damage was known in all but two cases, and flame damage was confined to the object of origin in 41 percent of the known cases. Flames spread beyond the room of origin in only 10 percent of the cases.

3.6 Time of Fire

As table 4 indicates, the time of fire is distributed differently for each component involved in ignition. Some patterns, such as light fixture fires occurring predominantly in the 6:00 p.m. to midnight period, are expected, but others, including the frequent occurrence of receptacle/outlet fires in the morning hours and of branch circuit fires in the afternoon and evening hours, are not so readily explainable. Attempts at examining these distributions have not produced promising hypotheses.

3.7 Occupant Condition

Occupant condition at the time of ignition, while not an NFIRS data element, was included on the incident report, and was known in 80 of the 105 cases. In 70 percent of these cases at least one occupant of the dwelling was awake and alert at the time of ignition. All occupants were asleep or impaired in 13 percent of the cases, and no one was home in 17 percent of the cases.

3.8 Comparison with National Fire Data

National fire-cause distributions can be estimated from data in the NFIRS, which contains computerized fire incident reports on fire causes and fire losses from over 30 states. An attempt was made to compare the distributions of several key elements with national estimates calculated from the NFIRS. Good correlation between national estimates and the study data was noted for the elements Fixed Property Use, Detector Presence and Equipment Involved in Ignition. Substantial differences were noted for the element Extent of Flame Damage. Finally, substantial differences found in two other key elements, Area of Origin and Form of Material Ignited, are believed to be due to differences in the application of the coding methodology. A discussion of each element follows.

Fixed Property Use in the study data base was divided into three categories - single family dwellings (excluding mobile homes), duplexes and small apartments (up to six units). The distribution of Fixed Property Use in the study data base was compared with the estimated national distribution of similar categories from NFIRS, and the results are illustrated in table 5. No major differences between the two data bases are noted.

Equipment Involved in Ignition, as indicated in table 6 (with unknowns excluded) did not show large variances between the study data base and national estimates. The nine Equipment Involved categories were generally in

Table 4. Time of Fire and Component Involved in Ignition

	Midnight - 6 a.m.	6 a.m. - Noon	Noon - 6 p.m.	6 p.m. - Midnight	All Hours
Service Components (14%)	20%	20%	27%	33%	100%
Branch Circuit Wiring (29%)	13%	13%	37%	37%	100%
Receptacles and Outlets (26%)	22%	37%	22%	19%	100%
Cords and Plugs (17%)	11%	17%	33%	39%	100%
Light Fixtures (13%)	14%	7%	29%	50%	100%
All Components (100%)*	16%	20%	30%	34%	100%

*Includes one low-voltage transformer case not included in other rows.

Table 5. Fixed Property Use Comparison

Fixed Property Use	CPSC	National Estimate
Single Family	86%	88%
Duplex	8%	5%
Apartment (up to six units)	7%	6%

Table 6. Equipment Involved in Ignition Comparison

Equipment	CPSC	Rank	National Estimate	Rank
Fixed Wiring	36%	1	39%	1
Cord, Plug	27%	2	19%	2
Switch, Receptacle, Outlet	15%	3	12%	3
Lighting Fixture, Lampholder	11%	4	12%	4
Lamp, Light Bulb	4%	5	7%	5
Overcurrent Protection Device	3%	6	6%	6
Other	2%	7	4%	7
Meter	1%	8	1%	8
Total	100%		100%	

the same proportions for both, and their rank order is the same. This indicates that the electrical components studied in detail here are represented in a similar manner to their relative national distribution as estimated from NFIRS.

As noted in section 3.4, Detector Presence was compared for the study data and national estimates and was found to be similar.

A substantial difference between national estimates and study data was noted when Extent of Flame Damage was compared as indicated by table 7.

It is obvious from both the percentage distributions and the rankings of Extent of Flame Damage that the study data base tends toward the smaller fires much more than those in the NFIRS. This may be an artifact of the case selection process. In this study, emphasis was placed on detailed investigation, so larger fires may not have been considered because extensive destruction of the site often precludes detailed investigation. On the other hand, all fires are supposed to be reported to NFIRS. This suggests that property loss figures from this study cannot be directly compared with national estimates.

The relatively high proportion (70 percent) of cases where occupants were awake and alert at ignition may also account in part for the relatively low level of fire damage in the subject cases.

Significant discrepancies between the study data and national estimates were found when Area of Origin and Form of Material Ignited were compared. They are believed to be artifacts of the coding procedure, however, resulting from a combination of more detailed and thorough investigation and analysis of the study cases than is usual for the fire incidents in NFIRS, and the resulting ability to use a more exacting application of the coding procedures in the study cases. In other words, the special-study codings are considered more reliable on a case-by-case basis than the NFIRS codings, although the distributions from the special study may be more or less representative than the NFIRS distributions.

4. OVERVIEW OF ELECTRICAL SYSTEMS

This section contains overview information from the detailed electrical fire investigation reports. Subsequent sections present more detailed information on selected parameters. These parameters are discussed separately from the incident report elements because, in some cases, similar parameters coded separately in the two reports are not directly comparable.

4.1 Electrical Component Involved in Ignition

Table 8 shows the Components Involved in Ignition for the 105 cases.

The first four categories (15 incidents) refer to utility system components tied to the particular building; they are usually located between the building's final overcurrent protection device and those utility system components not tied to a particular building. The four categories are referred to collectively as service components. In general, analysis of service com-

Table 7. Extent of Flame Damage Comparison

Extent of Flame Damage	CPSC	Rank	National Estimate	Rank
Object	41%	2	31%	1
Part Room	44%	1	20%	3
Room	9%	3	20%	3
Floor	6%	4	6%	5
Building	1%	5	21%	2
Outside Building	0%	6	2%	6
	100%		100%	

Table 8. Electrical Component Involved in Ignition

Component		Number of Incidents
Utility Supply Conductors		3
Overhead Utility Wires	3	
Service Entrance Wiring		7
Service Entrance Cable	4	
Service Entrance Conductors in Conduit	2	
Meter, Meter Box, Meter Mounting	1	
Service Equipment		4
Service Entrance Conductor Termination	1	
Grounding Electrode Conductor	1	
Service Disconnect	2	
Distribution Panel		1
Feeder Wiring	1	
Branch Circuit Wiring		30
Armored Cable (BX)	5	
Nonmetallic Sheathed Cable (Romex)	14	
Knob and Tube	9	
Multiple Types	2	
Cords and Plugs		27
Extension Cord	16	
Cord on Appliance	7	
Cord on Portable Lamp	1	
Christmas Tree Wiring	1	
Plug Adapter	1	
Cord-Heating Device	1	
Switch, Receptacle, Outlet		18
Wall Type Switch	1	
Receptacle, Outlet	16	
Baseboard Heater Thermostat	1	
Lighting Fixture, Lampholder		14
Fluorescent Lighting Fixture	1	
Incandescent Lighting Fixture	7	
Lampholder	3	
Portable Lamp	3	
Low Voltage Transformer		1
Low Voltage Transformer	1	
	Total	105

ponents was done on the group as a whole, as the limited number of fires involving each individual component precluded more detailed analysis even at an exploratory level.

Of the remaining components, branch circuit wiring provided the most cases, with nonmetallic sheathed cable and knob and tube dominating. Cords and plugs, in particular extension cords, contributed significantly to the total. Receptacles and outlets dominated their category, as did incandescent lighting. Some light fixture incidents were not electrical system breakdowns but were due to combustibles placed too close to otherwise normally operating lighting equipment; this will be discussed further in subsequent sections.

4.2 Alterations

Overall, 72 percent of the electrical systems in this study had been altered to some extent prior to the fire. These alterations ranged from minor (such as extension of a circuit) to major replacement or modification of system components. Some were system upgrades, such as replacement of deteriorated wiring or modernizing and upgrading system capacity, while others, such as addition of bootleg circuits, splicing improper wiring into circuits, or bypassing overcurrent protection devices had the effect of downgrading the system.

Several assessments were made in the second-phase analysis of the nature and effect of alterations. In the first-phase analysis, using the investigator's reports, it was estimated that 20 percent of the cases involved components that had been recently altered, rewired, replaced or installed. It was believed that this result understated the true extent of alterations and replacements, so in the second-phase analysis the full case files were examined and an independent assessment of alteration and replacement was made. Table 9 indicates the percentage of cases, overall and by type of component involved in ignition, that had alterations to the involved component or the involved circuit or that showed involved components or circuits that were not the original components or circuits. Although 72 percent of all systems had alterations, only 34 percent of involved components and 39 percent of involved circuits showed alterations. Sixty percent of cases showed replacement components, while 57 percent of cases showed replacement circuits. Light fixtures had by far the highest rate of component alterations (62 percent), while branch circuit wiring had by far the highest rate of circuit alterations (60 percent). Receptacles and outlets showed a low rate of component alterations (18 percent) but a high rate of replacement components (72 percent).

Table 9 also shows an assessment, overall and by component, of the effects of the alterations. Although some alterations were system improvements, none were judged to have helped in preventing, delaying or containing the fire. A negative effect—making ignition more likely or fire spread more likely, more widespread or more severe--was judged to have occurred in 82 percent of the cases, while 18 percent were judged to have produced no effect either way. Negative effects were most common for service components (100 percent), least so for receptacles and outlets (60 percent negative effect).

Table 9. Cases With Altered or Replacement Component or Circuit and Effects of Alterations

Component	Total Cases*	Alterations: Number of Cases Where It Was Known Whether Involved Component Was Altered	Percent Altered	Replacement: Number of Cases Where It Was Known Whether Involved Component Was Original	Percent Replacement
Service Components	15	15	27	14	43
Branch Circuit Wiring	30	26	38	24	63
Cords and Plugs	27	27	30	26	62
Receptacles and Outlets	18	17	18	18	72
Light Fixtures	14	13	62	12	42
All Components	105	99	34	95	60

Component	Total Cases*	Number of Cases Where It Was Known Whether Involved Circuit Was Altered	Percent Altered	Number of Cases Where It Was Known Whether Involved Circuit Was Original	Percent Replacement
Service Components	15	15	27	14	43
Branch Circuit Wiring	30	25	60	25	68
Cords and Plugs	27	27	33	27	48
Receptacles and Outlets	18	17	29	18	61
Light Fixtures	14	13	31	13	54
All Components	105	98	39	98	57

Component	Number of Cases Involving an Alteration Where Effect was Known	Percent Negative Effect	Percent No Effect
Service Components	4	100	0
Branch Circuit Wiring	15	87	13
Cords and Plugs	11	73	27
Receptacles and Outlets	5	60	40
Light Fixtures	8	88	12
All Components	44	82	18

*The low-voltage transformer component case is included only in the totals.

The other side of the alteration question is to ask whether the systems had had an unrecognized need for repairs prior to the fire. Table 10 shows that 58 percent did, ranging from 27 percent of systems where cords and plugs were the involved components to 80 percent of systems where service components were the involved components.

4.3 Prior Problems with System

Information on any problems involving the electrical system prior to the fire incident was recorded by the investigator through discussion with the building occupant. Some problems were noted immediately prior to (or simultaneous with) the ignition, while other problems appear to have occurred over extended periods of time.

Information on the presence or absence of prior problems was obtained in 97 percent of the cases; of these the existence of one or more prior problems was noted 44 percent of the time. Of the 45 cases with at least one prior problem, 69 percent had one, 22 percent had two, four percent had three, two percent had four, and two percent had five or more prior problems. Overall, in these 45 cases, a total of 65 specific problems were noted. Of the 18 different types of problems noted, the most common manifestation of a problem was fuses blowing, followed closely by light flickering.

The noted prior problems undoubtedly represent a lower bound of those actually occurring, because some respondents may not have remembered or may have omitted reference to prior problems. One indication that this may have occurred is that, although fuses blowing was noted as a problem by the occupant in only 18 cases, overfusing was noted by the investigator in 31 cases.

Table 11 lists the categories of prior problems noted and their frequencies. Some occurred singly, and others, as indicated earlier, occurred in combination.

Efforts were made to correlate the most frequent prior problems with the component involved in ignition, but no significant results were obtained. Correlations with age of building are discussed in section 6.

4.4 Code Violations

Another perspective on the overall status of the electrical system was obtained by investigator assessments of the presence or absence of code violations. As table 12 shows, 61 percent of the fires occurred in homes with code violations. This was least often the case for fires involving receptacles and outlets (39 percent) or service components (47 percent). It was most often true for fires involving light fixtures (86 percent) or branch circuit wiring (70 percent).

Table 13 shows the particular code violations, in order of frequency. Overfusing and overamping occurred in nearly half of all systems having a violation. The next two most frequent violations - improper splice and cord used to extend building wiring - are primarily or entirely problems of branch circuit wiring. (See the next section for the dominance of branch circuit wiring in splices.)

Table 10. Fire Incidents Where Electrical Systems Needed Repairs, by Component Involved in Ignition

Component Involved in Ignition	Total Cases	Number of Cases Where Need for Repair Was Relevant and Known	Percent Needing Repair
Service Components	15	15	80
Branch Circuit Wiring	30	28	75
Cords and Plugs	27	26	27
Receptacles and Outlets	18	15	60
Light Fixtures	14	13	46
All Components	105	98	58

NOTE: The one case involving a low-voltage transformer as the component is included only in the total.

Table 11. Summary of Prior Problems
(Prior Problems Noted in 44 Percent of the Cases)

Problem Description	Number of Times Cited
Fuses Blowing	18
Lights Flickering	14
Lights Dimming	7
Breakers Tripping	6
Appliances Operating Slowly	3
Bulbs Burning Out Prematurely	3
Radio Sounding Scratchy	2
Sparking, Arcing at Outlet	2
Lights Going Out	1
Previous Similar Fire	1
Unable to Turn Off Light	1
Smoke and Heat at Receptacle	1
Hot Cord	1
High Electric Bills	1
Lights Failing to Turn On	1
Range Burners Burning Out	1
Lights Turning On and Off Due to Vibration	1
Unspecified	1
Total	65

Table 12. Fire Incidents Where Code Violations Were Found, by Component Involved in Ignition

Component Involved in Ignition	Number of Cases*	Percentage with Violations
Service Components	15	47
Branch Circuit Wiring	27	70
Cords and Plugs	27	59
Receptacles and Outlets	18	39
Light Fixtures	14	86
All Components	102	61

*Not included are three branch circuit wiring cases where it was unknown whether a code violation was present. The low-voltage transformer case is included only in the totals.

Table 13. Frequencies of Code Violations

	Number of Cases	
Overloading	46	
Overfusing or overamping		31
Overloaded extension cords		9
Overloaded fixed wiring or circuit		4
Undersized replacement appliance cord		1
#14 nonmetallic sheathed cable used as subfeeder carrying 68 amps at 240 volts		1
Improper Extension of Building Wiring	14	
Cord used to extend building wiring		13
Extension cord spliced into building wiring		1
Cords or Wires Run in Wrong Places	15	
Cord stapled or attached to wall		5
Cord against or under furniture		2
Extension cord run through traffic area		2
Wire run through holes in wall		1
Cord run through hole in floor		1
Cord run through doorway		1
Cord run under rug		1
Overdriven staple on branch circuit cable		1
Lamp cord connected to surface		1
Exposed Wiring or Splices	7	
Open or unprotected splices		4
Outlet box contained bare, unused hot wires		1
Exposed wiring		1
Armored cable out of connector		1
Improper Grounding	7	
Ungrounded system		3
Neutral connected to ground terminal in receptacle		1
Loose ground		1
Ground wire cut off		1
Faulty connection of a homemade grounding clamp		1
Defeated or Missing Overcurrent Protection Device	4	
Penny behind fuse		2
Main circuit breaker bypassed		1
No overcurrent protection device		1
Other Mismatched Equipment and Improper Splices	18	
Lamps too large for marked ratings of fixtures		3
Several extension cords spliced together without boxes		2
Extension cord spliced to lamp cord without a box		1
Extension cords spliced in several places due to prior damage		1

Table 13. Frequencies of Code Violations (Cont'd)

Extension cord spliced to knob and tube wiring and used to wire a duplex receptacle		1
Spliced service entrance connectors		1
#16 and #18 cords spliced together without a box and on a 15 amp circuit		1
#14 and #12 wiring or cords spliced together on a 20 amp circuit		1
#14 knob and tube spliced to #12 nonmetallic sheathed cable on 15 amp circuit		1
#18, #14 and #12 wiring or cords all spliced together on 30 amp circuit		1
Industrial fluorescent fixture mounted directly to subfluor, connected with #18 wire spliced to #14 in open box		1
Pigtail from fixture looped to #14 wire without connector		1
Knob and tube circuit tapped into using a crimp connector improperly applied		1
Nonmetallic sheathed cable spliced to knob and tube using only WRAP		1
Splice using WRAP and tape		1
<u>Other Improper Installation</u>	<u>14</u>	
Bootleg circuits		3
Loose connections		2
Box mount fixtures secured to surface		2
Overtightened wire binding screw		1
Six wires on an ungrounded duplex receptacle		1
Two wires under one screw at fuse (double tap)		1
Electrical component mounted in inappropriate enclosure made of combustible materials		1
Homemade lamp socket connected to plug and inserted into receptacle		1
No bushing where cable entered box		1
Service entrance and meter socket covered with stucco (water collected)		1
<u>Other Violations</u>	<u>9</u>	
Unapproved electrical appliance fixed in place		1
Bad neutral at service entrance connection		1
Steel conductor		1
Unknown type		6

NOTE: Not shown here are four violations cited by local inspectors. These violations could not be confirmed with the National Electrical Code and may be local requirements. To maintain consistency, only violations identified by CFR using the case files are listed.

4.5 Fire Occurrence at Splice or Connection

The fire occurred at a wire termination, connection or splice in 33 percent of the cases. Of these, 97 percent were copper wiring and the remaining three percent (one case) were aluminum wiring. As indicated in table 14, receptacles and outlets were the components where fires most often occurred at a wire termination, connection or splice.

Further examination of this point showed that actual splices were a problem primarily for branch circuit wiring, as shown in table 15. Of the 10 splice cases involving branch circuit wiring, four involved nonmetallic sheathed cable, three involved knob and tube wiring, and the other three were divided among three other wiring methods.

4.6 Panel Board Location, Shelter from the Elements, and Ambient Conditions

The final overcurrent protection device for the branch circuit was in a panel board located on the exterior of the building in 32 percent of the 90 fires that did not involve service components. A panel board installed in the interior of the building was provided in the other 68 percent of these cases. Fused systems were located inside the building slightly more often than circuit breakers. Shelter from the elements was provided in 86 percent of the 29 cases with a panel board located on the exterior of the building. No shelter was provided in 10 percent of the cases, and in three percent the presence or absence of panel board shelter was unknown.

In 96 percent of the 90 fires not involving service components, the ambient conditions at the panel board were judged to be normal for the area and time of year. Two cases (two percent) were judged unusually hot, and two cases (two percent) were judged unusually damp.

4.7 Wiring Method, Material and Size

Of the 90 fires not involving service components, nonmetallic-sheathed cable (type NM, "Romex") was used in 48 percent of the cases, knob and tube in 27 percent, electric metallic tubing (EMT) and armored cable (type AC "BX") each in seven percent, and the remaining types of wiring, including multiple types in a single circuit, in one or two cases each.

Copper wiring was used in 94 percent of the cases, aluminum wiring in four percent and steel wiring in one percent. Most of the aluminum wiring (three of the four cases) was found in housing built in or after 1965, and aluminum wiring accounted for three of the 11 post-1964 cases (27 percent) not involving service components. Table 16 shows the breakdown by component.

Nonmetallic-sheathed cable was used in the steel wiring case and three of the four aluminum wiring cases; the fourth aluminum wiring case used service entrance cable. The steel conductor case was especially puzzling since steel conductors were never allowed by any code or standard and no one contacted had ever heard of steel cable being manufactured - even in wartime when copper was scarce. Luckily in this case, a sample was provided verifying the presence of the steel conductors.

Table 14. Fires Involving Splices, Connections or Terminations, by Component Involved in Ignition

Component	Percent of Fires at Splice, Connection, Termination
Service Components	13
Branch Circuit Wiring	40
Cords and Plugs	26
Receptacles and Outlets	56
Light Fixtures	29
Transformer	0

Table 15. Fires at Splices, by Component Involved in Ignition

Component Involved in Ignition	Percent of Fires at Splices
Service Components	0
Branch Circuit Wiring	31
Cords and Plugs	7
Receptacles and Outlets	5
Light Fixtures	7
Transformer	0

Table 16. Copper Versus Aluminum Wiring, by Component Involved in Ignition, for Post-1964 Housing

Component Involved in Ignition	Copper Wiring	Aluminum Wiring	Total Cases
Branch Circuit Wiring	0	0	0
Cords and Plugs	3	1	4
Receptacles and Outlets	2	2	4
Light Fixtures	3	0	3
Total	8	3	11

Table 17 shows how the presence or absence of system alternations varies by type of wiring method. The distribution of wiring methods is fairly close to the expected distribution, given usage patterns in the 10 cities.

Table 18 shows the distribution of wiring method by component involved in ignition.

Table 19 shows the relative frequency of wiring sizes of the involved branch circuit conductors for all cases not involving service components, for the smallest AWG size present in the circuit (Part A) and for the various combinations found (Part B).

4.8 Specific Component Failure Causing the Fire

Table 20 shows the distribution of components whose failure caused the fire by each of the major groups of components involved in ignition. For each of these 89 cases (service components and the single transformer case are excluded), the description of the component whose failure caused the fire was provided in a narrative, and the resulting 79 types of component failure descriptions were organized into the 23 major groupings shown on the table. Several analyses have been performed using these groupings, as described in sections 8-12, and the tabulation in table 20 provides some insights in itself. (For example, over half of the lighting fixture fires - those involving overlamping or combustibles too close - do not involve failures within the electrical system.)

4.9 Presence and Effect of Grounding

The presence and effect of grounding for the system and the involved circuit were examined for the 90 cases not involving service components. The absence of grounding was established for either the system or the involved circuit or both in 62 cases, as shown in table 21. Of these, the absence of grounding was a factor in six cases — two involving only ungrounded circuits and four involving ungrounded systems and circuits.

5. CHARACTERISTICS AND PERFORMANCE OF OVERCURRENT PROTECTION DEVICES

The distribution of cases among the different types of overcurrent protection devices is as shown in table 22. Edison-base fuses and circuit breakers dominated, and most of the analyses in this section concern only them. Type "S" fuses are of interest because they cannot be overfused, but because only one such case was found, it is included with Edison-base fuses in all subsequent analyses.

Considering only fires that did not involve service components and only fuses (both types) versus circuit breakers, there were 48 circuit breaker cases (55 percent) and 39 fuse cases (45 percent). This contrasts sharply with an expected split of 39 percent circuit breakers and 61 percent fuses, based on each city's relative usage of fuses versus circuit breakers, as reported to Carolyn Kennedy, CPSC, by city officials and the International Association of Electrical Inspectors.

Table 17. System Alterations, by Wiring Method

Wiring Method	Number of Cases	Percent	Percent Expected*	Percent with Alterations
Nonmetallic Sheathed Cable	43	48	53	70
Knob and Tube	24	27	29	71
Electric Metallic Tubing	6	7	4	50
Armored Cable	6	7	2	100
Other**	11	12	12	91
Total	90	100	100	73

*Based on estimated percentages of use of each wiring method, by city. Data obtained by Carolyn Kennedy, CPSC, from city officials and the International Association of Electrical Inspectors.

**The category "other" includes individual conductors in both rigid and flexible metal conduit, and those cases where more than one type of wiring was used within the involved circuit. For percent expected, "other" refer to systems with combinations of two or more wiring methods.

Table 18. Wiring Method and Component Involved in Ignition

	Percentage of Wiring Methods					
	Nonmetallic Sheathed Cable	Knob and Tube	Armored Cable	Electric Metallic Tubing	Other*	Number of Cases
Branch Circuit Wiring	43%	27%	0%	17%	13%	30
Cords and Plugs	33%	33%	19%	0%	15%	27
Outlets and Receptacles	61%	17%	6%	0%	17%	18
Lighting Fixtures	64%	29%	0%	7%	0%	14

	Percentage of Components Involved in Ignition				
	Branch Circuit Wiring	Cords and Plugs	Outlets and Receptacles	Lighting Fixtures	Number of Cases
Nonmetallic Sheathed Cable	31%	21%	26%	21%	42
Knob and Tube	33%	38%	12%	17%	24
Armored Cable	0%	83%	17%	0%	6
Electric Metallic Tubing	83%	0%	0%	17%	6
Other*	36%	36%	27%	0%	11

*The category "other" includes individual conductors in both rigid and flexible metal conduit, and those cases where more than one type of wiring was used within the involved circuit.

Table 19. Branch Circuit Conductor Wire Sizes (A.W.G.)

A. Wire Size Distribution (Smallest AWG Size in Circuit)

Wire Size		Number	Percent
6		2	2
8		2	2
10		2	2
12		21	23
14		57	63
16*		1	1
18*		1	1
Unknown		4	4
	Total	90	100

B. Combinations of Wire Size

		Number of Cases
6 only		2
8 only		2
10 only		1
12 only		20
14 only		51
10 and 8		1
12 and 10		1
14 and 12		6
16 and 12		1
18 and 14		1
Unknown		4
	Total	90

*These cases, where smaller than normal wire was found within branch circuits, had power cord/lamp cord spliced directly into the involved branch circuit.

Table 20. Failure Mode by Component

		Number and Percent of Component
A.	Branch Circuit Wiring (34% of Total)	
	Mechanical damage or improper installation (e.g., stapled, abraded, nailed, cut, other)	8 (27%)
	Poor or loose splice (e.g., loose splice, crimp, different wire types)	8 (27%)
	Ground fault (e.g., water, ungrounded armored cable, deteriorated insulation)	3 (10%)
	Use of improper wiring in circuit (e.g., steel, stranded)	3 (10%)
	Knob and tube encapsulated	3 (10%)
	Miscellaneous overload (e.g., overloaded, short in range)	2 (5%)
	Unknown	3 (10%)
B.	Cords and Plugs (30% of Total)	
	Mechanical damage or poor splice (e.g., to extension cord or appliance cord)	10 (37%)
	Overloaded extension cord	6 (22%)
	Overloaded plug	2 (7%)
	Damaged plug (e.g., loose blade connector)	2 (7%)
	Miscellaneous -- plug (e.g., short, water)	2 (7%)
	Miscellaneous -- cord (e.g., deteriorated insulation, electric blanket cord)	4 (15%)
	Unknown	1 (4%)
C.	Receptacles and Outlets (20% of Total)	
	Loose or poor connection	8 (44%)
	Mechanical damage (e.g., cracked, fire)	3 (17%)
	Overloaded	2 (11%)
	Miscellaneous (e.g., deteriorated, miswired, plug inserted improperly)	2 (11%)
	Unknown	3 (17%)
D.	Lamp and Lighting Fixtures (15% of Total)	
	Loose or poor connection or splice, miswiring	5 (36%)
	Combustibles too close (e.g., ballast, cloth fixture, towel, insulation)	5 (36%)
	Overlamped	3 (21%)
	Miscellaneous (e.g., deteriorated insulation)	1 (7%)

Note that the failure mode descriptions are highly dependent on the main component, that is, mechanical damage to branch circuit wiring may be of a different nature than mechanical damage to cords.

Table 21. Presence and Effect of Grounding

Was the System Grounded?	Was the Involved Circuit Grounded?	Was the Lack of Grounding a Factor?	Number of Cases
Yes	Yes	--	20
Yes	Unknown	--	2
Unknown	Yes	--	3
Unknown	Unknown	--	3
Yes	No	Yes	2
Yes	No	No	40
Yes	No	Unknown	2
No	No	No	4
No	No	Unknown	5
Unknown	No	No	5
		Total	90

Table 22. Type of Overcurrent Protection Device

Type of Device	Number of Fires	Percent of Fires
Circuit Breakers	49	47
Edison Base Fuses	39	37
Type "S" Fuses	1	1
Cartridge Fuses	0	0
No Device Present	1	1
Not Applicable*	13	12
Unknown	2	2
Total	105	100

*In 13 of the 15 service component cases, the fire occurred outside the building's overcurrent protection device, and so the type of device in use may not have been relevant. In the other two service component cases, there were two separate outside main breaker panels and the fire occurred in the connection between them; therefore the type of devices used in these main breaker panels were relevant for those cases.

5.1 Performance of the Overcurrent Protection Devices

An analysis was done of the possibility that some fuses and circuit breakers failed to activate because the circumstances of the fire were such that activation should not have been expected. Each case was reviewed and judgments were made as to whether activation should have been expected, to prevent ignition. Cases where activation would not have been expected generally were cases involving a poor ground or a loose connection, both of which are conditions that prevent an overcurrent condition from occurring at the overcurrent protection device. Table 23 gives the results of this review, and it shows that in most cases activation should not have been expected. Of the 80 cases where an assessment was possible, only four (all fuses) would have been expected to have activation to prevent ignition. (Note that these expectations did not address the possibility of ignition at a remote location permitted by a slow-acting or nonperforming overcurrent protection device.)

Of the 40 fuses, 16 (40 percent) interrupted the current, while 18 (45 percent) did not. For the remaining six fuses, three (eight percent) were believed to have operated only because fire attacked the circuit, and the other three (eight percent) had unknown performance. Of the 49 circuit breakers, 15 (31 percent) interrupted the current, while 24 (49 percent) did not. For the remaining 10 cases, two (four percent) were believed to have operated only because fire attacked the circuit, and the other eight (16 percent) had unknown performance.

Problems with the overcurrent protection devices were checked under two headings - tampering and unusual conditions. Tampering generally referred to conditions intended to defeat the overcurrent protection device, such as overfusing (or the analogous condition for circuit breakers, overamping), putting a penny or other metal insert behind a fuse, wrapping a fuse with foil, or having no protective device at all. Unusual conditions included all the conditions covered under tampering and other problem conditions, such as exposed wiring, poor workmanship, ground cut-offs, double taps, and bootleg or jackleg circuits. ("Bootleg and jackleg circuits" are terms used on the west and east coasts, respectively, to refer to multiple problems of a kind associated with installations made by persons not knowledgeable of electrical systems and codes.)

Tampering and unusual conditions found at the panel were almost universal for the fuses. Of the 40 fuses, 33 (83 percent) were tampered with, four (10 percent) were not, and the tampering status was unknown for the other three panels (seven percent). Similarly, unusual conditions were noted at the panel in 35 (88 percent) of the cases, while three (seven percent) had none noted, and the other two (five percent) were unknown. Of the 33 cases of tampering, 32 (97 percent) involved overfusing; the other case involved a penny behind the fuse. Two of the cases with overfusing also involved a penny behind the fuse.

By contrast, unusual conditions at the panel were not found for most circuit breakers and tampering was comparatively rare. Of the 49 circuit breakers, four (eight percent) were tampered with, and 42 (86 percent) were not. The tampering status was unknown in the other three cases (six percent). Similarly, unusual conditions were noted in 12 (24 percent) of the cases and were not found in 36 (73 percent) of the cases. The other one (two

Table 23. Overcurrent Protection Device Performance Versus Expectations

Expectation		Number of Cases*	Activated	Did Not Activate	Believed Activated by Fire Attacking Circuits or Unknown	Percent Activated**
			Fuses (Edison Base or Type "S")			
Should it have operated to prevent ignition?	Yes:	4	1	2	1	33
	No:	33	13	14	6	48
			Circuit Breakers			
Should it have operated to prevent ignition?	Yes:	0	0	0	0	-
	No:	43	13	22	8	37

*Excluded from these sections are cases where no determination was possible on whether the device should have operated, and the 16 cases where type of overcurrent protection device was unknown or not applicable.

**Percentage based on total, excluding cases where device was believed to have activated only because fire attacked the circuit or had activation status unknown.

percent) was unknown. All four cases of tampering involved overamping (i.e., overfusing of circuit breakers). In two of these cases the circuit breakers did automatically trip initially, but occupants reset them.

Of the 16 cases not cited as involving fuses or circuit breakers, one of the two cases with device cited as unknown was also cited as overfused and was stated to have been reset. The one case with no device was cited for tampering in that the circuit was left unprotected. Table 24 shows the type of unusual panel conditions cited.

In summary, the vast majority (76 of 80) of incidents involved conditions where the overcurrent protection device would not have been expected to prevent ignition. In a minority of these incidents, the overcurrent protection device did eventually activate but only after fire initiation had occurred.

5.2 Overcurrent Protection Devices by Component Involved in Ignition

Table 25 shows how the type, problems and performance of overcurrent protection devices varied across the four major types of components involved in ignition. Fires involving branch circuit wiring, cords and plugs, and lighting fixtures were fairly evenly distributed between fused and circuit-breaker-protected systems, but fires involving switches and receptacles were three times as likely to be circuit-breaker-protected as fuse-protected. This correlates with the fact (noted later in this report) that switch and receptacle fires were much more evenly distributed by building age than were other fires, and the newer buildings, which tended to have lower rates of all other types of fires, were also much less likely to have fuses. System alterations were more common in branch circuit wiring fires than in fires involving other types of components. Tampering and unusual panel conditions were noted less often in cord and plug fires and switch and receptacle fires than in branch circuit wiring or lighting fixture fires.

5.3 Overcurrent Protection Device Rating by Minimum Wire Size of Branch Circuit

Table 26 compares the rating of the overcurrent protection device to the smallest AWG size of the wire used in the branch circuit conductors supplying current to the component involved in ignition. Thirty-three (89 percent) of the 37 fuse cases with copper wiring of known size showed overfusing, but only two (5 percent) of the 43 circuit breaker cases with copper wiring of known size showed overamping.* The overall percentage with overamping was 44 percent. Two of the three aluminum wire cases with known wire size also showed overamping.

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*This is based on the following criteria: For copper wire, 14 gauge wire can support up to 15 amps, 12 gauge wire up to 20 amps, 10 gauge wire up to 30 amps, 8 gauge wire up to 40 amps, and 6 gauge wire up to 50 amps. For aluminum wire, 12 gauge wire can support up to 15 amps and 8 gauge wire up to 30 amps.

Table 24. Incidence of Unusual Conditions Found at Panel
(Unusual Conditions were Noted in 53 Percent of the Cases)

Fuses

A. Individual Conditions	Total Number of Conditions Cited	Percent of Total
Overfusing	34	54
Ground cut-off	8	11
Bootleg/jackleg circuits	7	11
Double taps	6	9
Poor workmanship	5	8
Defeated	2	3
Fused neutral	1	2
	63	100

B. Combinations of Conditions	Number of Cases	Percent of Total
Overfusing alone	15	42
Overfusing and double taps	4	11
Overfusing and ground cut-off	4	11
Overfusing and bootleg/jackleg circuits	2	6
Overfusing and poor workmanship	1	3
Overfusing and defeating	1	3
Overfusing, double taps and bootleg/jackleg circuits	2	6
Overfusing, poor workmanship and ground cut-off	2	3
Overfusing, bootleg/jackleg circuits, and ground cut-off	1	3
Overfusing, poor workmanship and bootleg/jackleg circuits	1	3
Overfusing, poor workmanship and fused neutral	1	3
Defeated, bootleg/jackleg circuits and ground cut-off	1	3
	35	100

Table 24. Incidence of Unusual Conditions Found at Panel (cont'd.)

Circuit Breakers

A. Individual Conditions	Total Number of Conditions Cited	Percent of Total
Poor workmanship	7	33
Ground cut-off	4	19
Bootleg/jackleg circuits	4	19
Overamping	2	10
Double taps	1	5
Fused neutral	1	5
Defeated	1	5
Exposed wiring	1	5
	21	100

B. Combinations of Conditions	Number of Cases	Percent of Total
Overamping alone	2	17
Poor workmanship alone	1	8
Fused neutral	1	8
Bootleg/jackleg circuits	1	8
Poor workmanship and ground cut-off	2	17
Poor workmanship and bootleg/jackleg circuits	1	8
Defeated and ground cut-off	1	8
Poor workmanship and exposed wiring	1	8
Poor workmanship, double taps and bootleg/jackleg circuits	1	8
Poor workmanship, bootleg/jackleg circuits and ground cut-off	1	8
	12	100

Other

Unknown device: 1 with overfusing, poor workmanship and bootleg/jackleg circuits

1 with poor workmanship and bootleg/jackleg circuits

No device present: 1 with unprotected circuits, exposed wiring and bootleg/jackleg circuits

Table 25. Overcurrent Protection Devices, by Component Involved in Ignition

	Fuses	Circuit Breakers	Combined
A. Branch Circuit Wiring			
Number of Fires	17	13	30
Fires	57%	43%	100%
Tampering	82%	17% (of 12)	57% (of 29)
Unusual Panel Conditions	88%	31%	63%
System Alterations	82%	85%	87%
Device Interrupted Current	71% (of 14)	38% (of 8)	50% (of 22)
B. Cords and Plugs			
Number of Fires	11	15	26
Fires	42%	58%	100%
Tampering	88% (of 8)	0% (of 14)	32% (of 22)
Unusual Panel Conditions	90% (of 10)	20%	48% (of 25)
System Alterations	64%	67%	65%
Device Interrupted Current	40% (of 10)	54% (of 13)	48% (of 23)
(One case, not shown above, involved a device of unknown type.)			
C. Switches and Receptacles			
Number of Fires	4	13	17
Fires	24%	76%	100%
Tampering	100%	15%	35%
Unusual Panel Conditions	100%	23%	41%
System Alterations	50%	77%	71%
Device Interrupted Current	50%	30% (of 10)	36% (of 14)
(One case, not shown above, had no overcurrent protection device.)			
D. Lighting Fixtures			
Number of Fires	7	7	14
Fires	50%	50%	100%
Tampering	100%	0%	50%
Unusual Panel Conditions	100%	29%	64%
System Alterations	71%	57%	64%
Device Interrupted Current	0% (of 5)	29%	17% (of 12)

Note: The numbers in parentheses indicate that the percentages in question are based on less than the full number of cases. Such entries reflect exclusions of unknowns (i.e., unknown whether tampering was present, unknown whether unusual conditions were present, or unknown whether device interrupted current) and exclusions of cases where the overcurrent protection device was believed to have operated only because the fire attacked the circuit.

Table 26. Wire Size and Overcurrent Protection Device Rating by Type of Device

(Smallest AWG Size in Circuit)

	AWG Wire Size 6	8	10	12	14	16/18*
Fuses						
15 amp	0	0	0	1	2	0
20 amp	0	0	0	1	6	0
25 amp	0	0	0	2	4	0
30 amp	0	0	0	2	18	1
40 amp	0	0	0	0	0	0
50 amp	0	0	0	0	0	0
Total	0	0	0	6	30	1
Circuit Breakers						
15 amp	0	0	0	4	24	0
20 amp	0	0	1	9	1	1
25 amp	0	0	0	0	0	0
30 amp	0	0	0	0	0	0
40 amp	0	1	0	0	0	0
50 amp	2	0	0	0	0	0
Total	2	1	1	13	25	1
Combined Data						
15 amp	0	0	0	5	26	0
20 amp	0	0	1	10	7	1
25 amp	0	0	0	2	4	0
30 amp	0	0	0	2	18	1
40 amp	0	1	0	0	0	0
50 amp	2	0	0	0	0	0
Total	2	1	1	19	55	2

Note: These figures cover only copper-wire cases and exclude the service component cases. Also excluded are one case where the type of device was unknown, one Edison-base fuse case where the rating of the fuse was unknown, and one circuit breaker case where the wire sizes were unknown.

The four aluminum wiring cases involved two with 20 amp circuit breakers and 12 gauge wire, one with a 30 amp circuit breaker and 8 gauge wire, and one with a 60 amp circuit breaker and wire of unknown size. The one steel wiring case involved a 20 amp fuse and 14 gauge wire.

*These cases, where smaller wiring than normal was found within branch circuits, had power cord/lamp cord spliced directly into the involved branch circuit.

Table 27 provides a further examination in terms of whether the overcurrent protection device operated, given the type of device, the rating of the device and the size of the wire.

6. THE ROLE OF BUILDING AGE

Older buildings accounted for a disproportionately large share of the fires examined, but building age was highly correlated with several other factors, so there is no clear indication of which factor(s) was the leading element in raising the risk of electrical distribution fire. Table 28 shows the increase in fire rate as building age increased. The fire rate for housing constructed in the 1950s is about equal to the fire rate for all housing, which is nearly three times the fire rate for housing built in the 1960s and 1970s and just over half the fire rate for housing built before 1940.

6.1 Age of Building Versus Ages of System, Circuit and Component

Some attempts were made to examine age measures more closely related than building age to the electrical system, particularly those parts involved in fire. Age of last alteration was examined for systems that had been altered, but age was available for only 14 cases, as shown in table 29. Of these, 11 had been altered within 10 years of the fire. In fact, 10 had been altered within five years of the fire. Ages of involved component and involved circuit also were determined, but 42-48 percent of the cases had unknown ages. For those that were coded, the median age of involved component was 9.5 years and the median age of involved circuit was 15 years.

6.2 Fuses and Circuit Breakers by Age of Building

Fuses were phased out of most housing after 1950, and this is borne out by an examination of the use of fuses versus circuit breakers in pre-1950 versus post-1950 buildings. Of the 28 fires in buildings built between 1950 and 1980, 22 buildings (79 percent) had circuit breakers while only four (14 percent) had fuses, and no building built after 1959 had fuses. Two had power company fuses. By contrast, of the 73 fires in buildings built before 1950, 34 (47 percent) had fuses and 26 (36 percent) had circuit breakers. A total of 10 had power company fuses only, one had an unknown type of device, and one had no device. Thus, the housing stock of the pre-1950 period shows slightly greater presence of fuses than circuit breakers, while the housing stock of post-1950 shows fuses to be a minor factor.

The problem noted earlier involving failures of untampered circuit breakers to interrupt the current was slightly more prevalent in older housing. In six of the 19 fires (32 percent) involving untampered circuit breakers in housing built in or after 1950, the current was interrupted by the circuit breakers. Correspondingly, in five of the 22 fires (24 percent) involving untampered circuit breakers in housing built before 1950, the circuit breakers acted to interrupt the current. (Included in the base are five cases where it was not determined whether the circuit breaker had operated and two cases where the fire attacked the circuit and this was believed to have caused the circuit breaker to operate. These seven cases split fairly evenly, four before 1950 and three after.)

Table 27. Overcurrent Protection Device Performance, by Type and Rating of Device and Wire Size - Percentage of Cases Where Device Interrupted Current

(Smallest AWG Size in Circuit)

	AWG Wire Size			
	6/8/10	12	14	16/18
Fuses				
15 amp	*	100% (of 1)	50% (of 2)	*
20 amp	*	0% (of 1)	60% (of 5)	*
25 amp	*	100% (of 1)	33% (of 3)	*
30 amp	*	50% (of 2)	40% (of 15)	0% (of 1)
40 amp	*	*	*	*
50 amp	*	*	*	*
Circuit Breakers				
15 amp	*	50% (of 4)	44% (of 18)	*
20 amp	*	13% (of 8)	100% (of 1)	100% (of 1)
25 amp	*	*	*	*
30 amp	*	*	*	*
40 amp	*	*	*	*
50 amp	50% (of 2)	*	*	*
Combined				
15 amp	*	60% (of 5)	45% (of 20)	*
20 amp	*	11% (of 9)	67% (of 6)	100% (of 1)
25 amp	*	100% (of 1)	33% (of 3)	*
30 amp	*	50% (of 2)	40% (of 15)	0% (of 1)
40 amp	*	*	*	*
50 amp	50% (of 2)	*	*	*

*No such cases

Note: Excluded from this table are all the cases excluded from table 27 and all cases where either the fire caused the device to operate or it was unknown whether the device operated.

In the aluminum wiring case with unknown wiring size, it also was unknown whether the circuit breaker operated. In the other three aluminum wiring cases, the circuit breaker did not operate. In the steel wiring case, the fuse did operate.

Table 28. Ratio of Electrical Fires to Housing Units, by Age of Housing

Year of Construction	Age of Housing in 1980	Estimated Percentage* of All Housing Units with that Age	Percentage of** Fires in Housing of that Age	Index-Ratio*** of Fires to Housing Units
1970-79	1-10 yrs	21.8	6.9	0.32
1960-69	11-20 yrs	21.5	6.9	0.32
1950-59	21-30 yrs	14.7	13.9	0.95
1940-49	31-40 yrs	11.0	14.9	1.35
Pre-1940	Over 40 yrs	31.0	57.4	1.85
	Total	100.0	100.0	1.0

* The percentage distribution for housing units built before 1970 is based on Census figures for housing units in the cities used in the study, i.e., of all housing built before 1970 in those cities, 27.4 percent was built in 1960-69, 18.9 percent in 1950-59, 14.1 percent in 1940-49, and 39.6 percent before 1940. Because similar figures for those particular cities were not available for the period of 1970-79, the national Census figure of 21.8 percent was used, and then the study cities' distribution of pre-1970 housing units was prorated over the 78.2 percent of all housing built before 1970. A check of national figures for pre-1970 periods suggest the cities' distribution is not significantly different from the national distribution [2].

** Based on 101 study fires. This total excludes three fires where building age was not recorded and the only fire in Oakland. The latter was excluded on the theory that it would not be appropriate to include all the housing units in Oakland in the building age just to accommodate one fire.

*** The index indicates how much higher or lower than the overall fire rate was the fire rate for a particular building age cohort.

Table 29. Age of Building versus Ages of Alteration, Involved Component, Involved Circuit

	Number of Cases			
Age (Years)	Age of Building	Age of System Alteration	Age of Involved Component	Age of Involved Circuit
1	0 (0%)	4 (29%)	9 (17%)	4 (7%)
2-10	7 (7%)	7 (50%)	21 (39%)	18 (30%)
11-15	5 (5%)	1 (7%)	2 (4%)	5 (8%)
16-20	2 (2%)	1 (7%)	2 (4%)	4 (7%)
21-30	14 (14%)	1 (7%)	7 (13%)	9 (15%)
31-40	15 (15%)	0 (0%)	4 (7%)	6 (10%)
Over 40	57 (57%)	0 (0%)	9 (17%)	14 (23%)
Total	101 (100%)	14 (100%)	54 (100%)	60 (100%)
Unknown, not applicable or alterations not completed	3	90	50	44

Percentages are based on all cases where ages were known. The Oakland case is excluded from all age-related analyses for reasons given in table 28.

Tampering with the overcurrent protection device is correlated with building age primarily because use of fuses is correlated with building age, as figure 1 demonstrates. Of the 26 fires in buildings built in 1950 or after and having fuses or circuit breakers, three of the four buildings with fuses were tampered with, while only one of the 22 buildings with circuit breakers were tampered with. This gives an overall tampering rate of at least 15 percent (four out of 26). (The qualification "at least" is needed because in two circuit breaker cases the report did not indicate whether tampering had occurred.) Of the 60 fires in buildings built before 1950 and having fuses or circuit breakers, 28 of the 34 with fuses were tampered with while only three of the 26 with circuit breakers were tampered with, producing an overall tampering rate of at least 52 percent (31 out of 60). (Again, the result is qualified because in four fuse cases and one circuit breaker case it was not determined whether tampering had occurred.)

The pattern for unusual conditions (overfusing, poor workmanship, double taps, bootleg circuits, etc.) found at the panel closely paralleled the pattern for tampering; both were correlated with building age primarily because the most common unusual condition found, overfusing, is more common for fuses than circuit breakers and fuses are more common in older buildings. Of the 26 fires in buildings built in 1950 or after and having fuses or circuit breakers, unusual conditions were found at the panel in three of the four buildings with fuses, while they were noted in only four of the 22 cases with circuit breakers. This gives an overall unusual conditions rate of at least 27 percent for buildings built in 1950 or later. (This qualification is needed because in one of the circuit breaker cases, it was unknown if unusual conditions existed.) Of the 60 fires in buildings built prior to 1950 and having fuses or circuit breakers, unusual conditions were found in 30 of the 34 cases with fuses compared to seven of the 26 with circuit breakers. This gives an overall unusual conditions rate of at least 63 percent for buildings built prior to 1950, again most likely due to the frequency of overfusing found. (The qualification is needed because in one fuse case and one circuit breaker case, it was unknown whether unusual conditions were present.)

6.3 System Alterations by Age of Building

As expected, system alterations were rare in new buildings, common in somewhat older buildings, and almost universal in very old buildings. Of the 14 buildings built in the 1960s and 1970s, only five (36 percent) had had - alterations. Of the 54 buildings built in the 1930s, 1940s, and 1950s, however, 37 buildings (69 percent) had had alterations. And of the 33 buildings built prior to 1930, 31 (94 percent) had had alterations.

The other side of alterations is need for repair, and the need for repair showed a significant increase for buildings over 20 years old, as table 30 shows. When age of involved component or involved circuit is used as the measure, however, the increase in need for repair occurs closer to the 30-year point.

6.4 Components Involved in Ignition by Age of Building

Tables 31 and 32 show that the involvement of some classes of components changed dramatically at 1940 or at 1960. The most notable patterns are for

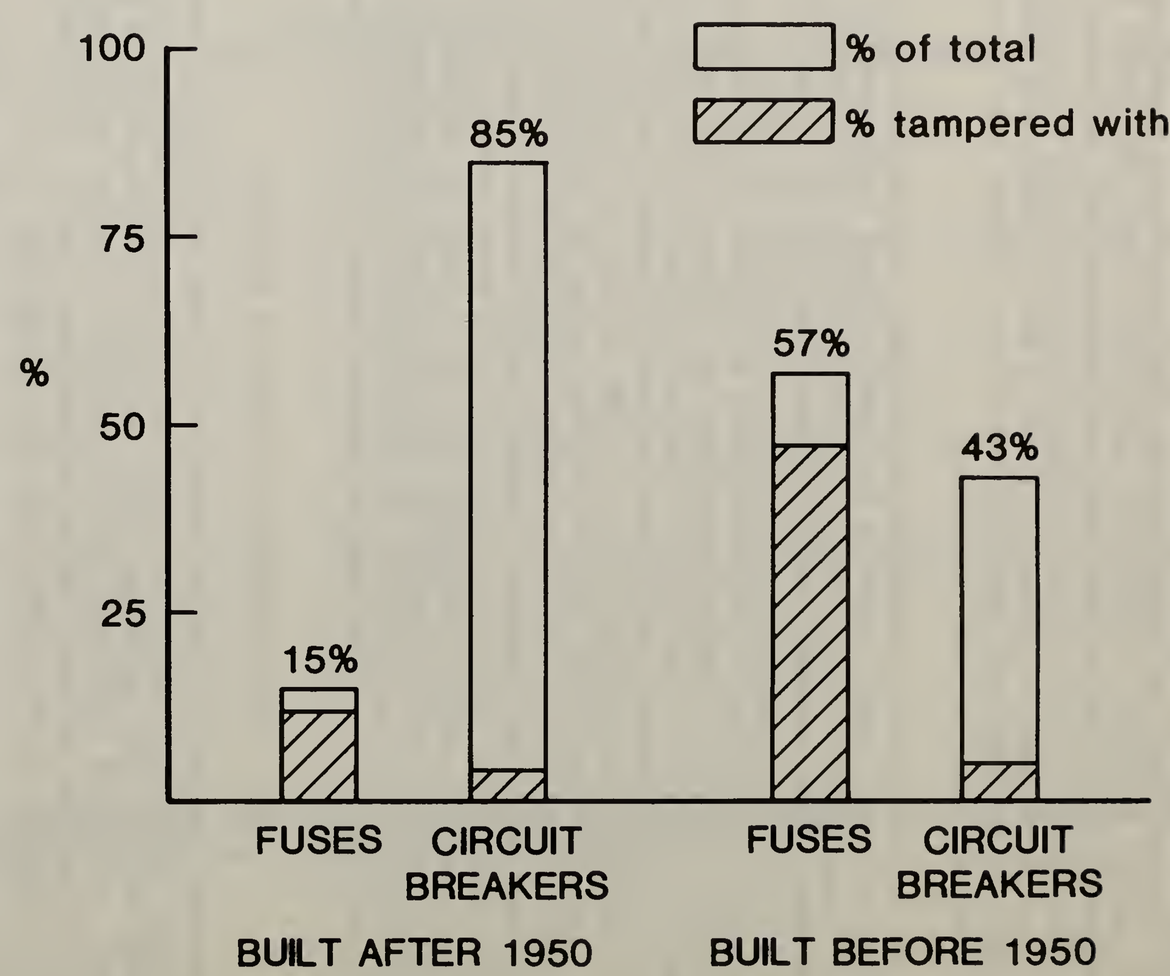

Figure 1. Tampering by Year Built and Type of Overcurrent Protection Device

Table 30. Need for Repair versus Age of Building, Alteration, Involved Component, Involved Circuit

	Number and Percentage Needing Repair			
Age	Age of Building	Age of Alteration	Age of Involved Component	Age of Involved Circuit
Up to 20 years	4 (27%)	9 (69%)	15 (47%)	12 (41%)
21-30 years	8 (62%)	1 (100%)	4 (57%)	4 (44%)
31-40 years	8 (57%)	23 (43%)	3 (75%)	4 (67%)
Over 40 years	36 (64%)	0 (--)	7 (78%)	9 (64%)

Excludes the Oakland Case and all cases where need for repair or the relevant age was unknown or not applicable.

Table 31. Ratios of Fire Rates for Post-1940 and Pre-1940 Housing, by Type of Component Involved in Ignition

Type of Component Involved in Ignition	Housing Units Built in 1940 Or After		Housing Units Built Before 1940		Ratio of Fire Rate for Pre-1940 Housing Units to Fire Rate for Post-1940 Housing Units*
	Number of Fires	Percent of Fires	Number of Fires	Percent of Fires	
Service Equipment	3	21	11	79	8.2
Branch Circuit Wiring	14	50	14	50	2.2
Cords and Plugs	10	37	17	63	3.8
Switches and Receptacles	10	56	8	44	1.8
Lighting Fixtures	6	46	7	54	2.6
All Components	43	43	58**	57	3.0

* This is given by the ratio of the prior-to-1940 and after-1940 percentages, divided by .449, which is the ratio of housing units built prior to (31.0%) and after 1940 (69.0%), as noted in table 29.

** The total includes one low-voltage transformer case, which does not fit with any of the major component groups.

Table 32. Ratios of Fire Rates for Post-1960 and Pre-1960 Housing, by Type of Component Involved in Ignition

Type of Component Involved in Ignition	Housing Units Built in 1960 or After		Housing Units Built Before 1960		Ratio of Fire Rate for Pre-1960 Housing Units to Fire-Rate for Post-1960 Housing Units*
	Number of Fires	Percent of Fires	Number of Fires	Percent of Fires	
Service Equipment	1	7	13	93	9.9
Branch Circuit Wiring	1	4	27	96	20.6
Cords and Plugs	4	15	23	85	4.4
Switches and Receptacles	5	28	13	72	2.0
Lighting Fixtures	3	23	10	77	2.5
All Components	14	14	87**	86	4.7

*This is given by the ratio of the prior-to-1960 and after-1960 percentages, divided by 1.309, which is the ratio of housing units built prior to (56.7 percent) and after 1960 (43.3 percent), as noted in table 29.

service equipment, which has a much larger share of its fires in pre-1940 housing than do the other component groups, and for branch circuit wiring, which shows a similar dramatic change in fire rate at 1960. At the other extreme, switches and receptacles show the smallest differences in fire rates between old and new buildings.

6.5 Wiring Method by Age of Building

Table 33 presents the distribution of wiring method by age of building, as given in the cases, and type of overcurrent protection device. The figures exclude service component fires and the single low voltage transformer fire; the figures on fuses include the type S fuse case. Nonmetallic sheathed cable was present in most of the fires in buildings constructed in or after 1950 and is nearly as common in fires in buildings constructed before 1950 as the leading wiring method, knob and tube. Circuit breakers were used primarily with nonmetallic sheathed cable, while fuses were used with nonmetallic sheathed cable and knob and tube wiring. When electric metallic tubing was used, it was solely with circuit breakers, and when armored cable was used, it was usually with fuses. The "other" category in table 33 is primarily made up of hybrid wiring systems, that is a mix of multiple wiring methods within the individual system.

7. THERMAL INSULATION

There were 17 cases coded as involving thermal insulation at the point of fire origin. No information was obtained on fires that could have involved insulation but did not (e.g., fires in the vicinity of insulation but which were not coded as having insulation involvement), so no estimate can be made of the percentage of insulation involvement in cases where that was a possibility.

Of these 17 cases, nine involved cellulose insulation, seven involved mineral fiber insulation, and one involved insulation of unknown type. Of the seven cellulose insulation cases for which the installation date was known, all had had the insulation installed within two years of the fire. Note, though, that significant use of cellulose insulation is a relatively recent phenomenon. Of the 16 cases involving known insulation types, one case of cellulose insulation and one case of mineral fiber insulation involved service components; a second case of mineral fiber insulation involved the one low-voltage transformer case.

Of the 14 cases involving non-service components and known insulation types, two of the cellulose-insulation cases were coded with failure mode and contribution to fire unknown or not applicable. That leaves six cases each of cellulose and mineral fiber insulation. All six cellulose-insulation cases involved encapsulation, that is, a heat buildup leading to fire caused by the fact that insulation surrounded the wiring. For half these cases, encapsulation was the only problem, while for half it occurred in combination with electrical problems. Two thirds of the mineral fiber cases involved encapsulation as the only problem; the rest involved only electrical problems. All six cellulose-insulation cases showed the insulation contributing to both early ignition and fire spread. Only one third of the mineral fiber cases contributed to both stages; the rest contributed only to early ignition.

Table 33. Wiring Method, by Building Age and Type of Overcurrent Protection Device

(Excluding fires in service components or low voltage transformers)

A. All Fires

Wiring Method	Circuit Breakers	Fuses	Other/Unknown	Total
Nonmetallic sheathed cable	60%	31%	50%	47%
Knob and Tube	13%	46%	0%	27%
Electric Metallic Tubing	13%	0%	0%	7%
Armored Cable	2%	13%	0%	7%
Other	13%	10%	50%	12%
Total	100%	100%	100%	100%
Number of Fires	48	39	2	89

(These totals include four fires not included below - three with age unknown and the one fire from Oakland, which is not included in any distribution by age for reasons given earlier.)

B. Fires in Housing Built Prior to 1950

Wiring Method	Circuit Breakers	Fuses	Other/Unknown	Total
Nonmetallic sheathed cable	42%	27%	50%	34%
Knob and Tube	23%	48%	0%	36%
Electric Metallic Tubing	15%	0%	0%	7%
Armored Cable	4%	12%	0%	8%
Other	15%	12%	50%	15%
Total	100%	100%	100%	100%
Number of Fires	26	33	2	61

C. Fires in Housing Built in or After 1950

Wiring Method	Circuit Breakers	Fuses	Other/Unknown	Total
Nonmetallic sheathed cable	86%	75%	--	84%
Knob and Tube	0%	0%	--	0%
Electric Metallic Tubing	10%	0%	--	8%
Armored Cable	0%	25%	--	4%
Other	5%	0%	--	4%
Total	100%	100%	--	100%
Number of Fires	21	4	0	25

Note: Percentages may not total to 100% because of rounding error.

Of the eight cellulose insulation fires not involving service components, six (75 percent) involved branch circuit wiring and two were light fixture fires. Of the seven mineral fiber insulation fires not involving service components, four (57 percent) involved branch circuit wiring, while the other three were evenly divided among receptacles, light fixtures, and low-voltage transformer.

8. SERVICE COMPONENT FIRES

As noted earlier, the category of service components consists of utility supply conductors, service entrance wiring, service equipment and distribution panels. Service components were cited as the component involved in ignition in 15 cases, or 14 percent of the total. As noted in section 5, service component fires were relatively rare in buildings under 40 years of age. None of the six cases involving service entrance wiring occurred in buildings less than 40 years old.

No consistent single failure mode or contributor was noted for service components. A total of five fires were attributed to deteriorated insulation, with water accumulation noted in three cases. In four cases the primary causal factor was given as improper installation of a recently altered system, resulting in a ground fault or overload condition. Alterations in progress were responsible for two additional fires, one resulting from accidental contact with high voltage lines, and one from the removal of support for the service entrance cable. Finally, four cases were essentially unknown, including two ground faults from unspecified failures.

One pattern of interest was by city. Akron accounted for 20 percent of the total cases but 53 percent of the service-component fires. Over a third of Akron's fires involved service components compared to eight percent for all other cities combined. We were unable to identify any special conditions in Akron that would account for this difference. It may be that the investigators in Akron were more attuned to these kinds of fires and therefore identified things the investigators in the other cities did not identify.

9. BRANCH CIRCUIT WIRING FIRES

Several aspects of fires involving branch circuit wiring have been discussed in earlier sections. Several additional tabulations are discussed here.

A total of 70 percent of the involved branch circuits contained at least some #14 AWG wire. This is roughly consistent with the wire size distribution across all cases listed in table 19.

Most of the involved branch circuits were 120 volt (90 percent) and 80 percent were general purpose (lighting and receptacle) circuits. The remainder were divided two-to-one between large and small appliance circuits.

In 12 cases (40 percent) one or more electrical components supplied by the involved circuit were noted to be "on" at the time of the fire. (In four cases (13 percent) it was indicated that no electrical components were "on" at ignition, and the remaining 14 cases (47 percent) were unknown.) The

connected circuit load on the involved branch circuit was known in only nine of those 12 cases and for those cases, it ranged from three watts to 2,160 watts.

Overloading of the circuit was unknown in eight of the cases. Of the remaining 22 cases, seven (32 percent) were noted to be overloaded. All of the involved branch circuits had been damaged electrically, damaged by the fire, or both. In addition, six were found to have been damaged mechanically, two were corroded and one had multiple types of damage noted.

Finally, of the specific component failures causing the fire, mechanical damage (most often by staples) and splice problems stand out.

10. CORD AND PLUG FIRES

Of the 27 fires involving cords and plugs, 16 (59 percent) involved extension cords, six were permanently attached appliance cords, four were detachable appliance cords and one was a Christmas tree light cord.

As indicated in table 32, cord and plug fires showed more of a fire-rate difference between pre-1940 and post-1940 buildings than did any other non-service component fires. This may be largely due to the use of extension cords to extend outmoded, inadequate or defective branch circuit wiring in older buildings. This hypothesis is supported by the fact that a cube tap or other device was used to extend the wiring of the building in 56 percent of the cases. Also in all 16 extension cord cases, the cords were noted to be replacing permanent building wiring.

The involved cord was plugged into a grounded receptacle in only six cases, four of which were in buildings less than 15 years old. All of the ungrounded receptacles were in buildings over 25 years of age, and 81 percent were in buildings over 40 years old.

Since the dominant problem in cords and plugs appears to be the use of extension cords to replace building wiring, the remaining analysis in this section focuses on them. The misused extension cords were also heavily used, compounding the problem. Of the 16 extension cords, eight were beng used daily, 24 hours per day; and another one was being used daily eight hours per day. A total of three were used daily, four hours per day; one was used daily, two hours per day; one was used about one hour per month; one had just been put into use; and one was used daily for an unknown time. This pattern of extensive operation was not very different from the pattern for appliance cords, where four of nine cords with known usage rates were in use 24 hours per day. Appliance cords, however, are often designed to stand up to heavy use.

One half of the 10 appliance cord failures were at the plug, while only one of the 16 extension cord failures occurred at the plug, possibly indicating that the weak link in extension cords is the cord itself. A total of 11 of the 16 extension cords were noted as lamp cord, while eight of the 10 cords used with appliances were noted to be the generally heavier duty applicance or power cords.

While all of the seven appliance cords where cord age was known were over seven years old, only two of the 12 extension cords of known age were over seven years old. The remaining 10 were no more than five years old, and four were one year old or less. This indicates that, unlike appliance cords, the effect of age in extension cords may be a secondary issue relative to the issue of use, and misuse, of the cords.

Except for the predominance of plugs and older cords, there was no clear pattern of specific failure mode for appliance cords. A clear pattern of misuse of extension cords is indicated, however. The specific failure mode was given as mechanical damage in 44 percent of the cases, overloading in 44 percent of the cases, and splicing in 12 percent. Although splicing was indicated as the specific failure mode in only two cases, at least seven and possibly eight of the 16 extension cords had been spliced (versus only one of the 10 appliance cords). The frequency of overloading fires is most likely explained by the use of the cords to replace or extend building wiring. The mechanical damage problem may be in part explained by cord location, as in 14 of the 15 cases where location was known, the extension cord was noted to be improperly located, often in multiple ways. A summary of the ways in which extension cords were improperly located is given in table 34.

The extension cord cases were reviewed in terms of whether ignition would have been prevented by a line fuse in the cord, increased wire size, improved insulation, or some combination of the three. Of the 16 cases, 11 would have had ignition prevented by a combination of line fuse and increased wire size, with improved insulation having no impact. These 11 cases typically involved (a) intermittent overloading by devices like irons and hand-held hair dryers that are not in continuous use and (b) encapsulation of the cord, which had large segments running under boxes or rugs, pinned to the wall by a mattress, or otherwise covered. Ignition would have been prevented if the cord were able to handle its peak loads (increased wire size) or able to shut off if it received a load it could not handle (line fuse). Of the other five cases, three would have benefited from improved insulation, specifically improved abrasion resistance, and a line fuse but did not need increased wire size. (One case would have benefited from all three modifications and one would not have benefited from any.) These three cases typically involved mechanically damaged cords located in heavy traffic areas.

11. SWITCHES, OUTLETS AND RECEPTACLE

Fires in receptacles were more evenly distributed over building age than fires in any other component involved in ignition, and this fact correlated with a higher than usual percentage of fires occurring in homes with circuit breakers. Terminations and connections were notable as problems, with at least nine of the receptacle fires occurring at a termination or connection. (Another case occurred at a splice, termination or connection, but it was unknown which of the three was involved.) This suggests that loose connections between the receptacles and the wiring played a leading role in ignition. Also, there was a notably low proportion of ungrounded receptacles.

11.1 Age of Building and Overcurrent Protection Devices

As noted in section 6, receptacle fires are much less concentrated among older buildings than are other fires. For all fires, the fire rate in pre-

Table 34. Details of Improper Location of Extension Cords

(Improper location noted in 93 percent of cases where location was known)

Nature of Improper Location	Frequency Noted
On floor in traffic areas	7
Attached to building surfaces with nails, staples	5
Through doorways, windows, etc.	4
Under clothing, rugs, refrigerator	4
Wrapped around objects	2
Through holes in walls, floors	2
Close to heaters, hot objects	1

NOTE: Some cords had more than one feature of improper location. The 25 location problems correspond to 14 cases.

1940 buildings is three times the fire rate in post-1940 buildings, but for receptacles the fire rate in pre-1940 buildings is less than twice as great. Buildings built in or after 1960 account for 28 percent of receptacle fires but only 11 percent of all other fires. This suggests that, relative to other parts of the electrical system, receptacles have a larger share of problems that are there from the beginning, as contrasted with problems that show up only after the passage of decades.

Since fuses were largely phased out after 1950, the use of circuit breakers correlates well with building age, and so receptacle fires show a significantly higher percentage of cases with circuit breakers present. Receptacles were protected by circuit breakers in 72 percent of the cases versus 22 percent by fuses and six percent (one case) with no device. This compares with 49 percent circuit breakers, 49 percent fuses and one percent other or unknown devices in all other cases not involving service components or low voltage transformers.

11.2 Problems with Splices and Connections

Receptacle fires accounted for a major share of fires at splices, terminations, and connections. For receptacle fires, 56 percent were at splices or connections, compared to 32 percent of all other fires, excluding fires involving service components or low-voltage transformers, where only 13 percent of fires were at splices or connections. Focusing on terminations and connections, 45-50 percent of receptacle fires occurred at such points, compared to 13 percent of fires involving service components or low-voltage transformers and 12-15 percent of all other fires. (The range reflects the fact that, for some fires occurring at a splice or termination/connection, it was unknown which was involved.)

If this pattern of fires at terminations and connections suggests a pervasive problem with loose connections, the specifics of components whose failure caused the fire strengthen that suggestion. Six of the 10 fires at splices or connections (nine of which were copper wiring) definitely involved loose connections. Two others had the component causing the fire listed as unknown or uncertain. The other two consisted of one case with an old, deteriorated outlet and one case with poorly installed aluminum wiring.

Of particular interest is the pattern for the four fires involving back-wired receptacles. The four back-wired receptacle cases represent approximately the expected proportion of the 17 receptacle cases where it was known how the receptacle was wired. Those four fires constitute 21 percent of the receptacle fires, whereas 16 percent of homes in the study cities have backwired receptacles, according to estimates provided by Carolyn Kennedy, CPSC, based on discussions with city officials and the International Association of Electrical Inspectors. Two of those four cases definitely involved a loose connection, and a third involved a fire at a splice or connection where the component causing the fire was uncertain.

11.3 Grounding

Of the 16 receptacle fires where it was known whether the receptacle was grounded, eight were grounded (50 percent) and eight were not. The eight that were grounded consisted of four with the grounding conductor going directly to

the receptacle, one each with the conductor going to an isolated screw in the outlet box or a grounding clip, and two involving some other arrangement.

Grounding was far more prevalent in newer buildings. In the seven buildings built in or after 1950, five (71 percent) had grounded receptacles - and it was 80 percent for the five buildings built in or after 1960 - while only three of the nine buildings built prior to 1950 (33 percent) had receptacle grounding. (These calculations exclude the three cases where it was unknown whether the receptacle was grounded.)

There were 12 cases involving metal outlet boxes where it was known whether the box was grounded; it was not grounded in 67 percent of those cases. The relationship to age was even more pronounced here. Of the four buildings built in or after 1950, three (75 percent) had grounded outlet boxes, while only one of the eight pre-1950 buildings (13 percent) did.

11.4 Other Factors

Several elements that had been considered likely to emerge as factors in receptacle fires did not. Only one of the fires involved a receptacle located near a heating unit and only one involved a receptacle surrounded by thermal insulation. As table 9 showed, receptacles and outlets accounted for the lowest percentage of alterations, although they did account for the highest percentage of replacement components and replacement circuits.

12. LIGHT FIXTURE, LAMPHOLDER AND PORTABLE LAMP FIRES

Of the 14 fires involving light fixtures, lampholders and portable lamps, 13 involved incandescent lights, and only one involved a fluorescent fixture. The failure of the fluorescent fixture was due to the ballast being installed too close to combustible material. Three of the remaining incandescent light fires also were not electrical in nature, as two were caused by the ignition of combustible material draped over lighted portable lamps, and the third was the ignition of a home-made macrame fixture due to over-heating. Of the remaining 10 fires, one resulted from a loose cord connection in a portable lamp and the other nine involved light fixtures permanently connected to building wiring.

Of these last nine fires, three were caused by overlamping of the light fixture, and one related to the encapsulation of a light fixture by cellulose insulation. Two cases involved porcelain lampholders - one caused by deteriorated insulation and the other by a loose connection - and one case was a jury-rigged metal and plastic fixture attached to the building wiring by lamp cord with taped splices. The remaining two fixtures were permanently connected; the failure mode was indicated as a loose splice in one, and in the other it was an improper crimp in the supply to the fixture which energized the fixture, igniting insulation. Of the last five cases (all electrical failures in permanently connected fixtures), two had been recently worked on, one had not, and the other two were undetermined.

13. CONCLUSIONS

This analysis of 105 electrical fires has identified a number of patterns that help to identify leading scenarios and factors in the ignition or

exacerbation of electrical fires. An important finding is that 61 percent of the cases involved apparent violations of the National Electrical Code (including its workmanship provisions), and these often were principal factors in the occurrence of the fire.

In analyzing whether overcurrent protection devices would have been expected to activate, it was found that of 80 cases where an assessment was possible, only four (all fuses) would have been expected to activate to prevent ignition. These four cases all involved tampering with the fuses, and in general tampering was widespread with fuses but not with circuit breakers. The cases where devices would not have been expected to activate generally involved loose connections or poor grounds, conditions that prevent overcurrent conditions from occurring at the device.

In examining patterns for particular classes of components, it was found that branch circuit wiring fires were much more likely in pre-1960 housing than in post-1960 housing. Over half the cord and plug fires were due to extension cords, always involving the use of extension cords to replace permanent building wiring. Extension cord failures, unlike failures involving other kinds of cords, tended to be in the cord rather than the plug. Most of these cords would have benefited from a line fuse in the cord combined with either increased wire size or improved insulation. Roughly half of all receptacle fires were at loose connections, compared to roughly one in seven of the other fires. There was some evidence that backwired receptacles have higher fire rates and more problems with loose connections, but there were too few such cases to support strong conclusions.

Service component fires were far more common in pre-1940 housing than in post-1940 housing, but they also were concentrated in one of the 10 study cities, suggesting that differences in the investigators' sensitivities may have played a role. The question of alterations was examined from several directions. Some beneficial alterations were found, but none of these helped to make ignition less likely or spread less widespread or less severe, and most alterations made the fire more likely, widespread, or severe. The analysis was limited, however, by the gaps in information on the histories of the involved electrical systems. Additional analysis of the system descriptions in the electricians' reports and summaries of overcurrent protection may shed more light on this topic.

These findings can serve as a basis for prioritizing further efforts on the nation's electrical fire problems.

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11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This report describes the results of an analysis of electrical fire cases by the Center for Fire Research, National Bureau of Standards for the Consumer Product Safety Commission. The report describes the 105 detailed electrical fire investigation reports from 10 participating cities and discusses findings resulting from analysis of the data from those reports. These findings include the effects of tampering, alterations and other system problems, factors that may cause overcurrent devices to fail to operate, the role of extension cords misused as permanent extensions of building wiring, the problems of loose connections between receptacles and wiring, and other scenarios and sequences of events that lead to electrical fire ignition.

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